

Atlantic sturgeon *Acipenser sturio* L., 1758 in the Guadalquivir River, Spain: A further contribution to its recent population dynamics and present decline

V. Fernández-Pasquier

C/ López Rubio, 1-3º C, E-18600 Motril, Granada, Spain. E-mail: pasquier@mbytesl.com

Received September 1999. Accepted June 2000.

ABSTRACT

Using as its starting point a major expansion of the historical data from the caviar and smoking plant that formerly existed in Coria del Río (southern Iberian Peninsula), some characteristics of this population are reviewed that were previously studied by other authors. A continuous series is presented of the annual captures of males and females from 1932 to 1969, as well as the evolution of the proportion of sexes and the average yearly weight. Using the space distribution of the locality of capture along the estuary and the springtime water flows, a locality index of capture for every year has been drawn up which enables us to know the possibility of successful reproduction for each spawning season. The faulty environmental conditions of the estuary at the species's recovery time, due to the progressive shortage of flow in the spring, and the bad quality of the water during the 1960s, made reproductive failure more and more frequent. Together with this, the pressure of fishing to which potential reproducers were subjected every spring in the lower estuary led to the practical extirpation of this population.

Key words: Databases, locality index, reproductive failure.

RESUMEN

*El esturión atlántico *Acipenser sturio* L., 1758 en el estuario del Guadalquivir: contribución al conocimiento de su reciente dinámica poblacional y actual declive*

Partiendo de una importante ampliación del registro histórico de datos de la fábrica de caviar y ahumados que existió en Coria del Río (Sevilla), se analizan algunas de las características de esta población que ya estudiaron otros autores. Se muestran las capturas anuales de machos y hembras desde 1932 a 1969 en una serie continua, así como la evolución de la proporción de sexos y el peso medio anual. Utilizando la distribución espacial de las localidades de captura a lo largo del estuario y los flujos de agua primaverales se obtiene un índice de localidad de captura para cada año que permite conocer la posibilidad de éxito reproductor para cada estación de freza. Las deficientes condiciones ambientales del estuario en la época de remonte de los peces, debido a la progresiva escasez de caudal en primavera, y la mala calidad del agua durante los años sesenta tuvieron como resultado el fallo reproductor cada vez más frecuente. Esto, unido a la presión de pesca a que se sometió cada primavera a los potenciales reproductores en la parte baja del estuario, tuvo como resultado la práctica extinción de la población.

Palabras clave: Bases de datos, índice de localidad, fallo reproductivo.

INTRODUCTION

Acipenser sturio L., 1758 was a common species in the Guadalquivir River during its upstream migration, reaching Córdoba, 230 km far away from the mouth of the river (Steindachner, 1866). Until the 1930s, the species was occasionally caught in the sea by trawlers (Classen, 1944) and by fishing lines near Sanlúcar de Barrameda. In 1932, a dam was finished at Alcalá del Río, 100 km away from the sea. It represented a barrier for the migrating fish, which could not reach the spawning areas above the dam.

A caviar and smoking plant was opened the same year in Coria del Río, 70 km from the river mouth. Until 1933, all migrating fish were captured with trammel nets close to the dam. In March 1933, the Ybarra company brought skilled fishermen from Romania, who built and installed the special fishing device which made it possible to work all around the estuary, and specifically in deep areas (from 6 to 11 m deep) in the lower estuary. This meant that the entire estuary could be accessible to fishermen, and fish could be captured from the brackish water to the spawning areas downstream from the dam. From that time on, every year in January fishermen sounded the river bottom and installed the fishing lines in deeper areas. The fishing effort was relatively uniform through the years, and the factory contracted six to eight pairs of fishermen for the harvest season. Each pair used 1 575 hooks divided into three lines. Captures started at the end of January in the lower estuary and ended in the middle of May.

The factory remained open until 1972, when catches were vanishing. The last records were in 1974 and 1975 (Hernando, 1975) and 1992 (Elvira and Almodóvar, 1993), one fish each year.

For a few years after the dam was built, local fishermen still continued catching young sturgeons in the lower estuary's muddy beaches, using the same kind of spoon nets they used for mullets (*Mugilidae*) (Classen, 1936, 1944; España-Cantos, 1948a, b, c).

The effects on sturgeon reproduction stemming from the fact that the dam was isolating their spawning areas and also controlling spring water flows were partially studied by Fernández-Pasquier (1999). The aim of the present work is to use the expanded database to analyse the population characteristics again, and try to find new reasons for understanding the decline of this population.

MATERIALS AND METHODS

So far Classen (1936, 1944), Rada (1954) and Muñoz-Goyanes (1959) have obtained the database used in the studies on the sturgeon population in the Guadalquivir estuary. Data from Classen between 1932 and 1943 and from original notebooks between 1944 and 1954 were studied by Elvira, Almodóvar and Lobón-Cerviá (1991). Subsequently, new original notebooks (with new data to 1967) were used by Fernández-Pasquier (1999).

The present paper represents a major expansion of that database, including the original notebooks of daily records of all the fish entering the caviar factory. This expansion of the original database consists of:

- Entries on all the males captured between 1944 and 1949, including date and locality of capture, life weight, and total length.
- Entries on all the females captured between 1944 and 1949 including date, locality of capture, life weight, and ovary weight.
- Entries on females from 1955 to 1972, including date, locality, total length, life weight, and ovary weight.

This important new data has been compared with information from several other sources. Therefore, we now have data on 3 098 females and 1 074 males in a series of 38 years of fishing. Among these data the most outstanding features are live weight, total length, locality of capture, date, and weight of the ovary, for almost the entirety of females taken between 1932 and 1969. Because the data on females have continuity over time, whereas data is lacking on males for some years, we made most of our analyses for females only.

The estuary was divided into seven sections (figure 1) from the mouth to the dam, respectively. Sections 1 and 2 were the deepest, highly influenced by seawater, with sandy and muddy bottoms and strong tidal flows. Sections 3, 4, and 5 were in the middle of the estuary, with muddy bottoms and brackish water. Sections 6 and 7 were characterised by continental water, low influence of tidal rhythms, and deep holes with gravel used as spawning areas after the dam construction.

First of all, we examined whether the improvements in database of historical registration confirm the theses of other authors. On the other hand the

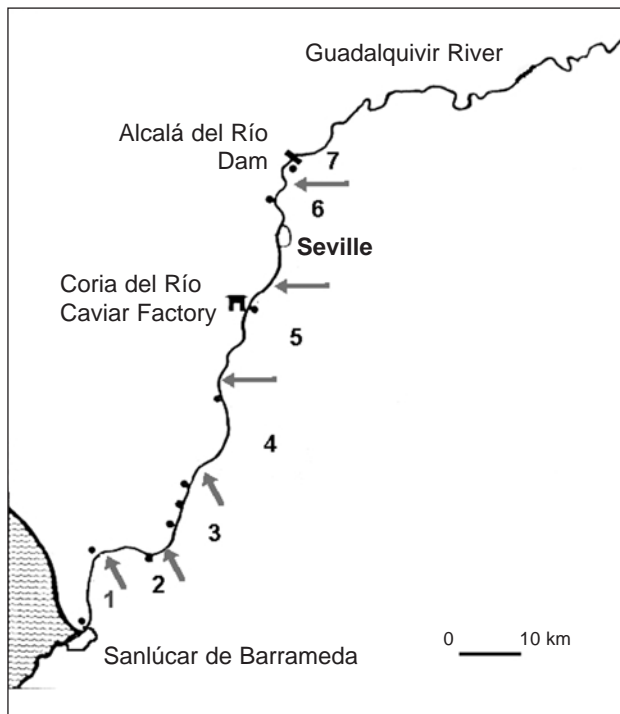


Figure 1. Map of the Guadalquivir estuary, localities and river sections. Modified from Elvira, Almodóvar and Lobón-Cerviá (1991)

important time sequence which we provide will enable us to study possible factors influencing the species's decline.

A χ^2 and a correlation rank test were used to study the sex ratio between the estuary sections. Spearman rank correlation coefficients were calculated to check relations between the adjusted average and water flows.

RESULTS

Evolution of captures and sex ratio

Between 1932 and 1972, the capture of 3 098 females and 1 074 males was recorded. Males caught in 1932, 1933, 1936, and 1941 were not recorded in the factory books.

The annual evolution of the captures is shown in figure 2, where a major annual increase in the first years can be seen, peaking in 1935 with the capture of 342 females, a figure that was never reached again. The captures in the late 1930s were very low, with the number of captured females staying below 100 until the early 1940s, a decade which saw the return of the previous stability in the captures. In the 1950s, a descending trend can be seen, reaching a critical point in 1962, with a drastic drop in captures below 20 females annually.

Figure 2 also shows the captures of males, highlighting that in several years they were not registered. Generally, the number of males was considerably lower than females, with important year-to-year differences. Although data on males is unavailable for the beginning of the fishery, and in the years of maximum captures of females (1934 and 1935) males were very scarce, later on there were years in which their number approached and even overtook that of the females. Although the evolution of the number of annual captures is different to that of the females, in both cases there are important year-to-

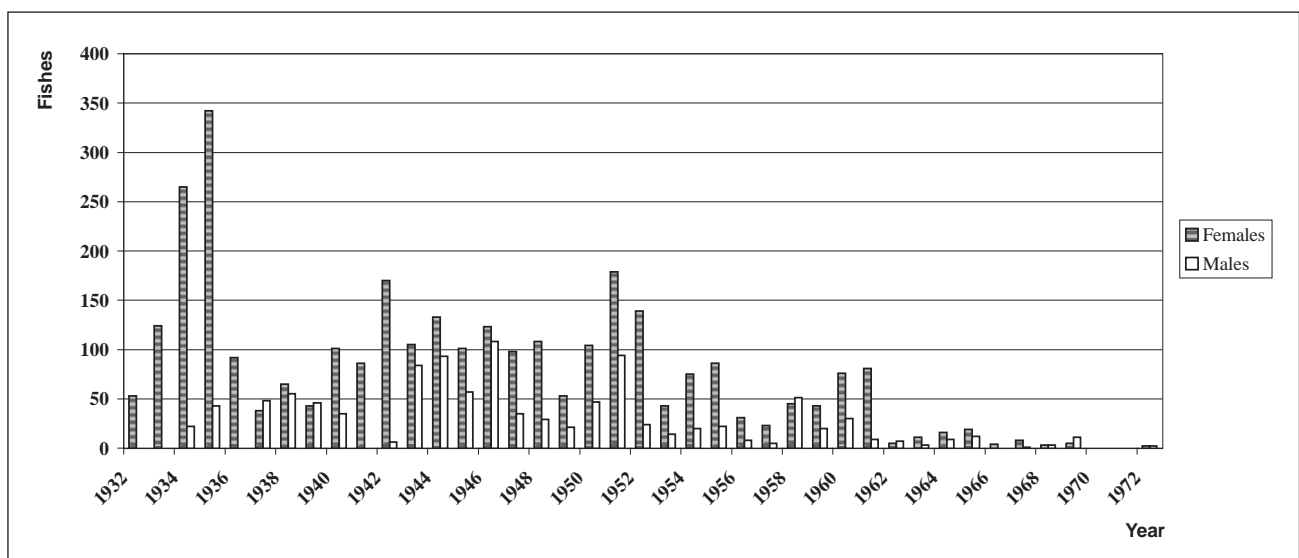


Figure 2. Annual variation of the number of captured fish

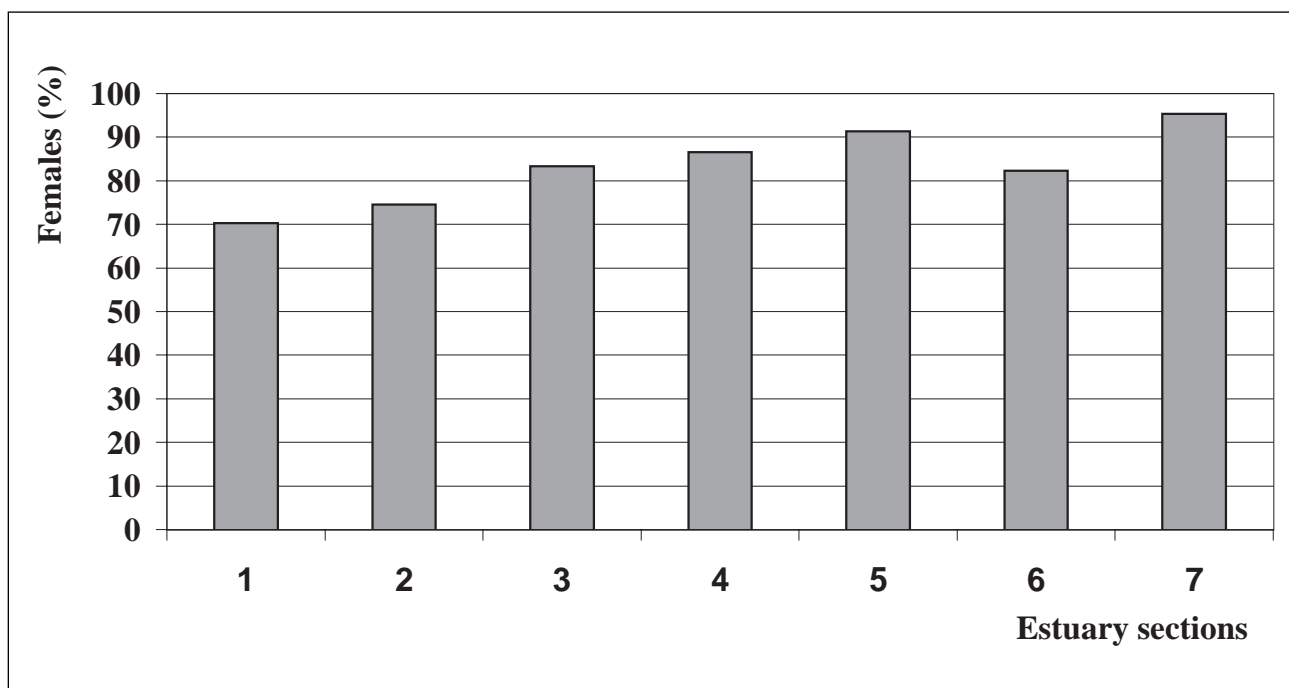


Figure 3. Percentage of females accounting for all the catches throughout 38 years in different sections of the estuary

year variations and a drastic decrease in captures starting from 1962.

In order to study space-time patterns, we divided the estuary into seven sections, from Elvira, Almodóvar and Lobón-Cerviá (1991), represented in figure 1. These seven sections, although they have several longitudes and their pressure of fishing varied, cover the entire available estuary for the species from the mouth to the spawning area, and they enable us to identify the zones of capture.

Figure 3 shows the percentage of females captured in each estuary section accounting for all the catches throughout 38 years. It stands out that the females always topped 70 % of total captures, with a tendency to increase this proportion closer to the dam, where they reached 96 % of the captures. These differences in sex ratios were statistically significant between sections ($\chi^2 = 116.6$; $p < 0.0001$), increasing progressively from sections 1 to 7 (correlation rank $r = 0.786$; $p = 0.036$).

Biometric characters

Table I shows biometric characters obtained from all fish recorded between 1932 and 1972. It is noteworthy that the average total length of the females was 36 cm higher than that of males, and that their average weight was exactly double.

A more detailed vision of the evolution of the average weight of the females over the years is shown in figure 4. The average weight of the captured females oscillated between 50 and 45 kg in the first 11 years of organised fishing. In the 12 following years, from 1942 to 1954, it had lower values, oscillating between 45 and 40 kg. Starting from 1954, there seems to be a recovery in the average weight, with annual values between 44 and 52 kg. From 1962 on, coinciding with the sharp drop-off in captures, larger inter-year weight differences can be seen, as well as a notable rise in the standard error.

Table I. Biometric characters of all fish recorded between 1932 and 1972

	Males			Females		
	Average	n	Standard error	Average	n	Standard error
Average weight	22.5	1 078	0.2	45.2	3 037	0.2
Average total length	150.5	621	0.3	186.6	2 551	0.3

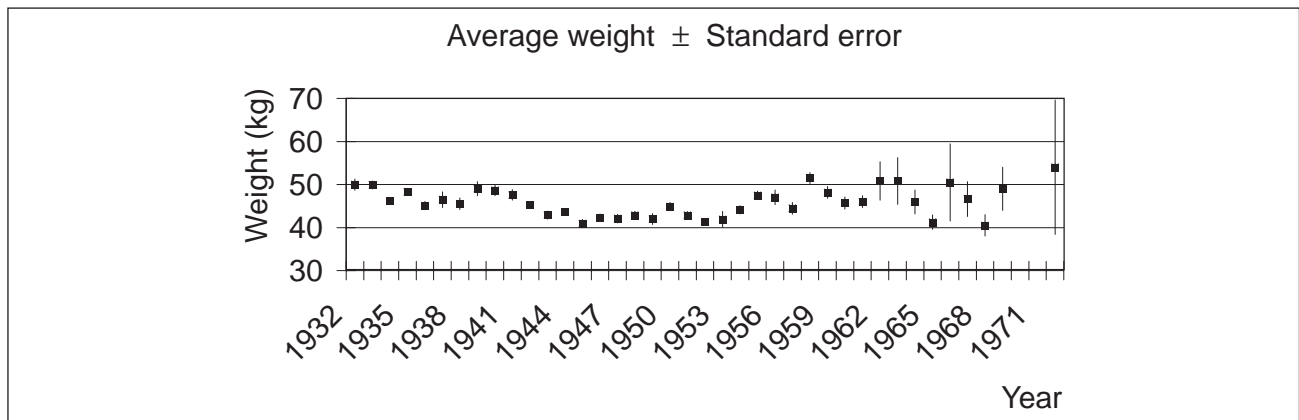


Figure 4. Yearly variation of the average weight of females between 1932 and 1972

Weight dispersion

In figure 5, the live weight of each female captured in the fishery is shown. We can see that in most years, individual weights vary widely, from 25

to 85 kg, with a lesser frequency of extreme values. The minimum weights take the shape of a well-defined curve, with two peaks corresponding to 1939 and 1958, which means scarcity of small-size breeders. The maximum weights were, in general, scat-

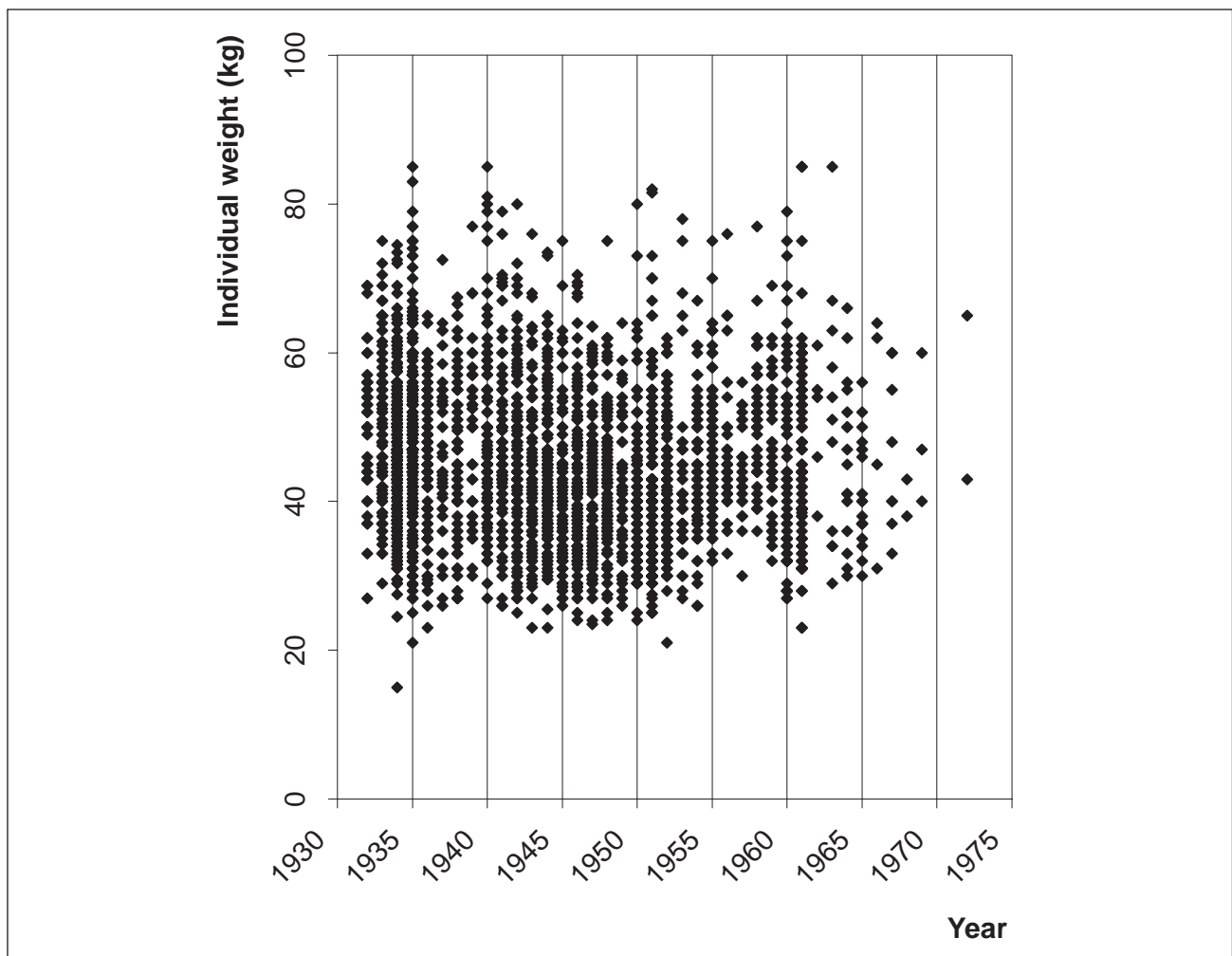


Figure 5. Weight of all the females captured for which data are available (n = 3 037)

tered more widely until 1962, with a lack of fish larger than 65 kg in some isolated years. The biggest fish captured weighed 85 kg.

It is noteworthy that during the years in which the catches were more important, reaching more than 100 females, the lower weights were more frequent than in years with a scarcity of captures. It is also evident that in 1962 there was a drastic drop in captures. The following years show weights more and more concentrated around the median values, with scarcity of both large and small fish.

Relations between locality index and water flows

Yearly adjusted average values from 1934 to 1969 were obtained with the number of females captured in each section of the estuary versus the number of their corresponding capture section from 1 (mouth) to 7 (dam). This yearly value, hereafter termed the locality index (LI), gave us an instrument to compare the relative success of each fishing section of the estuary from one year to another. A value of 1.5 for this LI means that most of the fish were captured in the lower estuary, and a value of 4 means that a relevant number of fish were cap-

tured overcoming the estuary. We do not use data from 1932 and 1933, because in both years the fishery was settled only in the Alcalá dam, since it was still not possible to capture fish in the lower estuary.

Therefore the LI shows a first period, 1934 to 1948, with an alternation in values between 1.5 and 4. From 1948 onwards, the totality of values is around 2 (except in 1968, with only two fishes captured in the season), meaning that the lower estuary produced most of the captures. In figure 6, the values of LI versus average water flows during the breeding season (March, April and May) are shown, measured at Alcalá dam. The strong similarity of both values from 1934 to 1948 is remarkable.

A Spearman rank correlation coefficient was fitted in between LI and water flow (table II). The results confirm the strong relationship between locality index and water flows, at least until 1961, when there were still important captures. After 1962, the relationships lose their strength. The relationship shows that fishes were captured throughout the estuary only in years of a wet spring; in years with a dry spring, catches occurred only in the lower estuary.

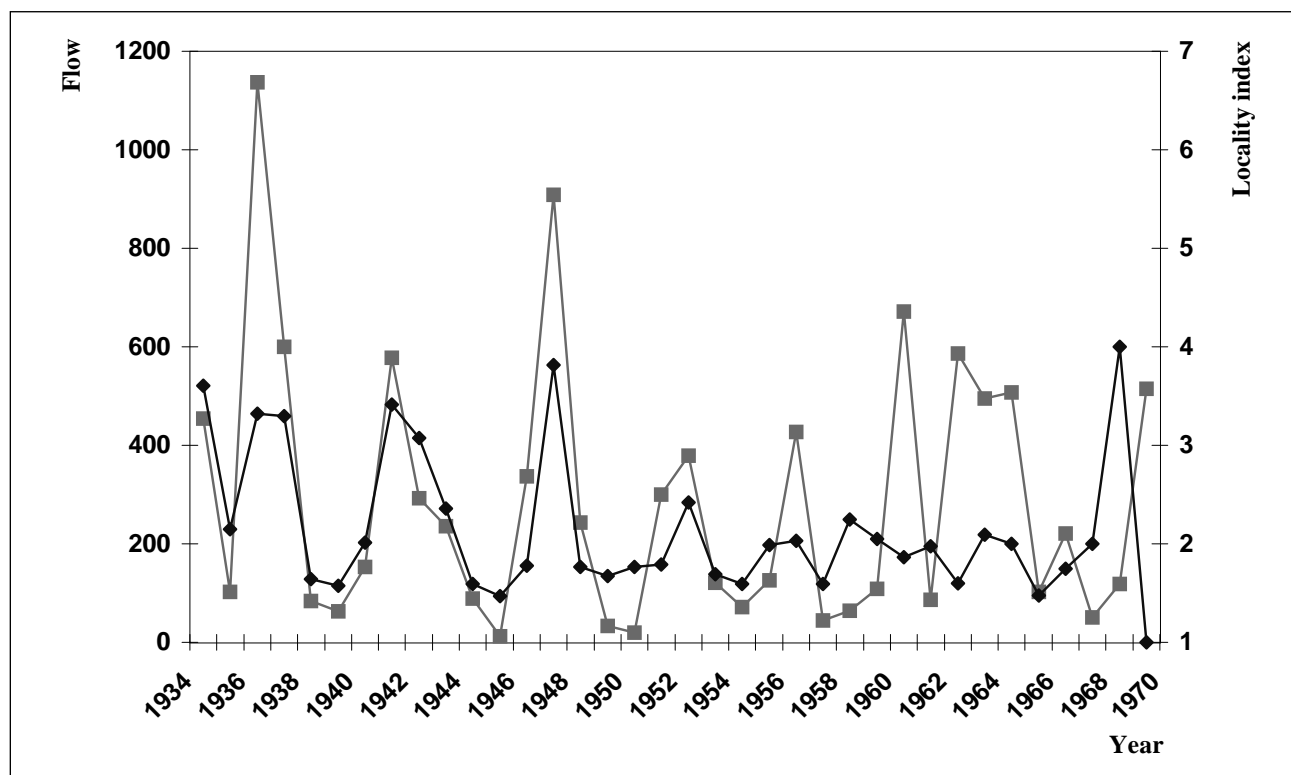


Figure 6. Locality index (◆) versus average (March, April, May) water flows (■) (m³/s)

Table II. Correlation between locality index and water flow

Rank	Correlation coefficient	p
1934-1948	0.8762	< 0.001
1934-1961	0.7206	< 0.0001
1934-1969	0.4545	0.0056

DISCUSSION

Average weight and total length for 1932-1972 are similar to the average weight and total length that have recently been reported for the Gironde population by Williot *et al.* (1997).

Yearly average weight from 1932 to 1954 has the same tendency remarked by Elvira, Almodóvar and Lobón-Cerviá (1991) after incorporating data on the weight of females from 1944 to 1949 lacking in their study. After 1954, the average annual weight suffered important variations. These variations of average weight and its corresponding standard error are associated with scarcity of captures, being particularly notable from 1962 onwards, when the standard error is discharged coinciding with a definitive shortage of captures.

Sex ratio (74 % F, 26 % M; $n = 4172$) is similar to those reported by Magnin (1962) for a five-year sampling period in the Gironde ($n = 96$), and by Elvira, Almodóvar and Lobón-Cerviá (1991) for the Guadalquivir captures from 1932 to 1943. The opposite ratio (74 % F, 24 % M) was reported by Williot *et al.* (1997) for catches of juveniles in the Gironde estuary. Juveniles have a similar size for males and females, and both have a similar chance to be captured by nets. In the case of adult fish, the ratios obtained were very probably an artefact of the selectivity of long lines, which capture females easier than males because they swim nearer to the bottom since the swimbladder is not functional when gonads are near maturity. Furthermore, in our database there are also four years in which no males were registered, which could have influenced the ratio.

The evolution of individual weight throughout the fishery indicates that there could have been two episodes in which new breeders failed to incorporate, before the definitive halt in captures: one at the end of the 1930s, and the other at the end of the 1950s.

The drastic scarcity of yearly catches from 1962 onwards must have been caused by pollution processes affecting both the entire estuary and

breeding stock. There are reports from fishermen (pers. comm.) describing overflows of black waters polluted by subproducts of olive oil. This pollution produced an escape of sturgeons near asphyxia swimming at the surface of the water towards the sea, killing other fishes recently captured in the meantime waiting on a line to be transported at the factory.

The magnitude of these processes of organic contamination was so heavy that they caused the practical disappearance of one of the main fishing resources of the estuary at this time. The shrimp *Palaemon longirostris* Milne-Edwards, 1837 disappeared for a period of three years, so that the fishermen who were dedicated to this species during the summer had to leave and seek employment in the countryside until this fishery was recovered.

The existing relationship between freshwater flows in spring and the annual LI means that only in wet springs could the fish have massively entered the estuary, and they were captured everywhere, from the mouth to the dam. The immediate consequence of this is that only in wet springs could fish get into spawning grounds with the turbid, fresh water needed for spawning (Fernández-Pasquier, 1999).

LI indicate that the last possibilities of breeding success could have occurred in 1947 and 1952, when the fish entered the estuary, even up to the spawning areas located in the proximity of the dam. In accordance with the age estimates of Classen (1943), females in the Guadalquivir estuary were 13 years old at first reproduction. Therefore, some small-sized females captured in 1960-1961 must have been first-time spawners belonging to a cohort of females which were born during the successful breeding season of 1947 (figure 5). The shortage of captures from 1962 on made it a little more difficult to appreciate the phenomenon again during the years 1965-1966, but it appears that it is probably more exact to estimate that females need between 12-14 years to get into the reproductive stock.

Reproductive failure became more and more frequent, especially from 1952 onwards, preventing the maintenance of a group of reproducers large enough to sustain the population. Due to this, and to more and more frequent reproductive failures (Vélez-Soto, 1951; Fernández-Pasquier, 1999), together with overfishing (Vélez-Soto, 1951; Gutiérrez, 1962; Lelek, 1980; Elvira, 1996; Fernández-Pasquier, 1999), the population was

heading for a definitive decline. Other factors, such as fishing of juveniles in feeding areas of the lower estuary (Classen, 1936; España-Cantos, 1948), destruction of spawning grounds because of gravel exploitation (Gutiérrez, 1962), and ovary parasites, all of them known although not quantifiable, had contributed, to a much lower extent, to the present decline of the species.

ACKNOWLEDGEMENTS

Thanks to Dr Benigno Elvira for the invitation to the Symposium on Conservation of Atlantic Sturgeon. Dr Carlos M. Herrera (Doñana Biological Station, CSIC) assisted me with the statistical analyses. He and an anonymous referee provided valuable comments on the earlier versions of the manuscript. Dr Carlos Granado-Lorencio supplied me with the data on water flows in Alcalá dam. Francisco Rodríguez, Antonio Rodríguez, José Díaz, and Antonio Gálvez, among others, all sturgeon fishermen from Trebujena, Coria and Sanlúcar, with their testimony and their original notes, introduced me to this fascinating species. Francisco and Eduardo Ybarra provided me with all of the extant books of original records from the caviar plant.

REFERENCES

- Classen, T. E. A. 1936. Notas preliminares sobre la biología y el aprovechamiento del esturión del Guadalquivir. *Publicaciones. Sección de Pesca, Ministerio de Agricultura, Industria y Comercio* ser. 1 (2): 15-41.
- Classen, T. E. A. 1944. Estudio bioestadístico del esturión o sollo del Guadalquivir (*Acipenser sturio* L.). *Trabajos. Instituto Español de Oceanografía* 19: 1-112.
- Elvira, B. 1996. Endangered freshwater fish of Spain. In: *Conservation of Endangered Freshwater Fish in Europe*. A. Kirchhofer and D. Hefti (eds.): 55-61. Birkhäuser Verlag, Basel.
- Elvira, B. and A. Almodóvar. 1993. Notice about the survival of sturgeon (*Acipenser sturio* L., 1758) in the Guadalquivir estuary (S.W. Spain). *Arch. Hydrobiol.* 129: 253-255.
- Elvira B., A. Almodóvar and J. Lobón-Cerviá. 1991. Sturgeon (*Acipenser sturio* L., 1758) in Spain. The population of the river Guadalquivir: a case history and a claim for a restoration programme. In: *Acipenser*. P. Williot (ed.): 337-347. Cemagref, Bordeaux.
- España-Cantos, J. 1948a. La pesca del esturión y la fabricación del caviar. *Caza y Pesca* 68: 466-468.
- España-Cantos, J. 1948b. La pesca del esturión y la fabricación del caviar. *Caza y Pesca* 69: 526-528.
- España-Cantos, J. 1948c. La pesca del esturión y la fabricación del caviar. *Caza y Pesca* 70: 589-591.
- Fernández-Pasquier, V. 1999. *Acipenser sturio* L. in the Guadalquivir river, Spain. Water regulation and fishery as factors in the stock decline from 1932 to 1967. *J. Appl. Ichthyol.* 15: 133-135.
- Gutiérrez, F. 1962. El esturión del río Guadalquivir. *Folleto informativo (Temas piscícolas)* 5: 1-58. Servicio Nacional de Pesca Fluvial y Caza. Pontevedra.
- Hernando, J. A. 1975. Notas sobre distribución de los peces fluviales en el Suroeste de España. *Doñana Acta Vertebrata* 2 (2): 263-264.
- Lelek, A. 1980. *Threatened freshwater fishes of Europe*. Council of Europe. Strasbourg: 269 pp.
- Lozano, J. J. 1956. Mutis del esturión sevillano. Una industria española que desaparece. *Caza y Pesca* 158: 108-109.
- Magnin, E. 1962. Recherches sur la systematique et la biologie des Acipensérides, *Acipenser sturio* L., *Acipenser oxyrinchus* Mitchill et *Acipenser fulvescens* Raf. *Annales Station Centrale d'Hydrobiologie Appliquée* 9: 7-242.
- Muñoz-Goyanes, G. 1959. *Informaciones estadísticas sobre la pesca continental en España*. Dirección General de Montes, Caza y Pesca Fluvial. Madrid: 143 pp.
- Rada, R. 1954. *Introducción a una estadística de pesca fluvial*. Dirección General de Coordinación, Crédito y Capacitación Agraria, Ministerio de Agricultura. Madrid: 140 pp.
- Steindachner, F. 1866. Ichthyologischer Bericht über eine nach Spanien und Portugal unternommene Reise. Zur Flussfischfauna des südlichen Theiles von Spanien und Portugal. *Sitzungsb. Akad. Wiss. Wien* 54: 261-272.
- Vélez-Soto, F. 1951. Observaciones sobre la pesca del esturión en el río Guadalquivir durante el año 1950. *Montes* 37: 33-40.
- Williot, P., E. Rochard, G. Castelnaud, T. Rouault, R. Brun, M. Lepage and P. Elie. 1997. Biological characteristics of European Atlantic sturgeon, *Acipenser sturio*, as the basis for a restoration program in France. *Environmental Biology of Fishes* 48: 359-370.